KU LEUVEN


# Recent results on francium isotopes at the collinear resonance ionisation spectroscopy (CRIS) setup.

Gregory Farooq-Smith

# Contents



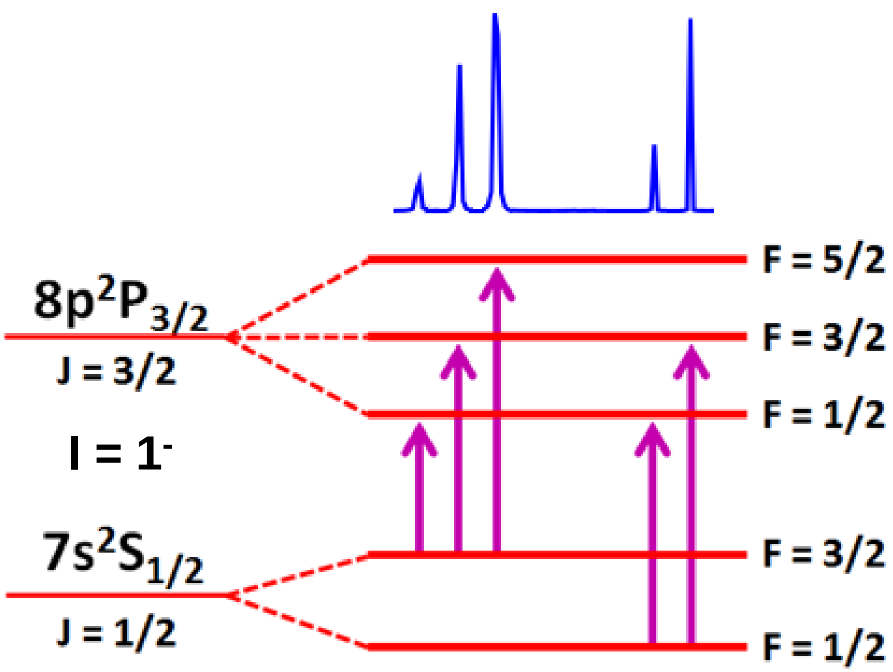


KU LEUVEN

# Laser Spectroscopy

- Hyperfine spectra can be examined by scanning the atomic transitions of an isotope with a laser.

- The extracted parameters can be related to fundamental nuclear properties of the isotope.

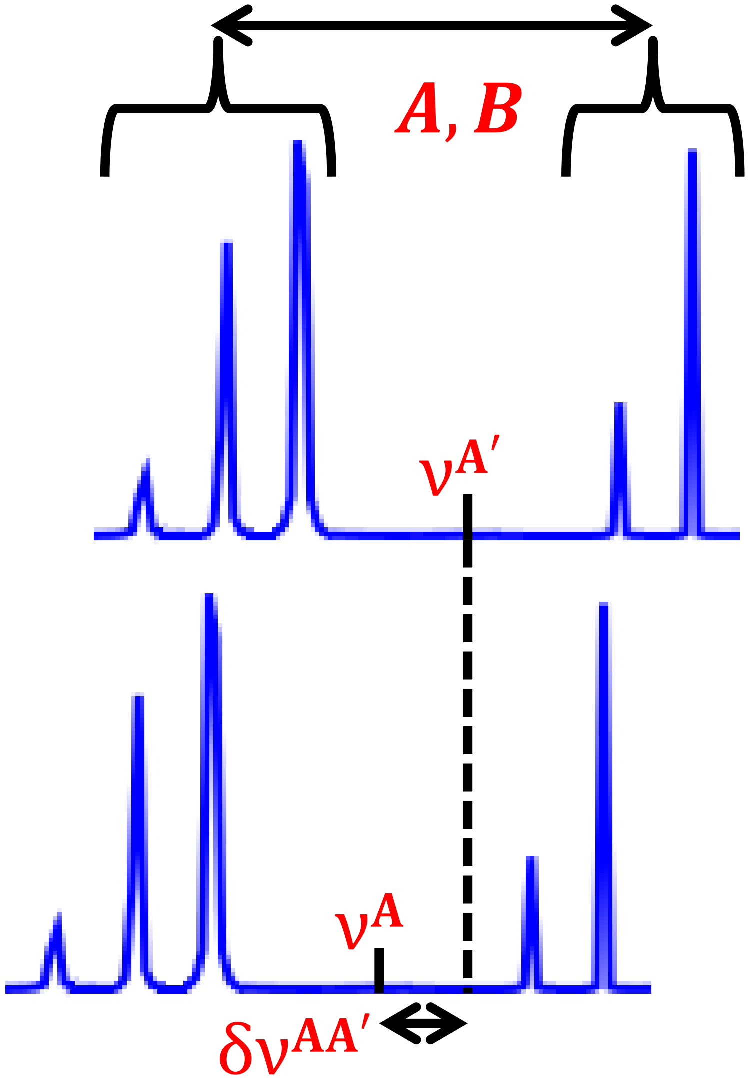



KU LEUVEN

# Laser Spectroscopy

- Hyperfine spectra can be examined by scanning the atomic transitions of an isotope with a laser.

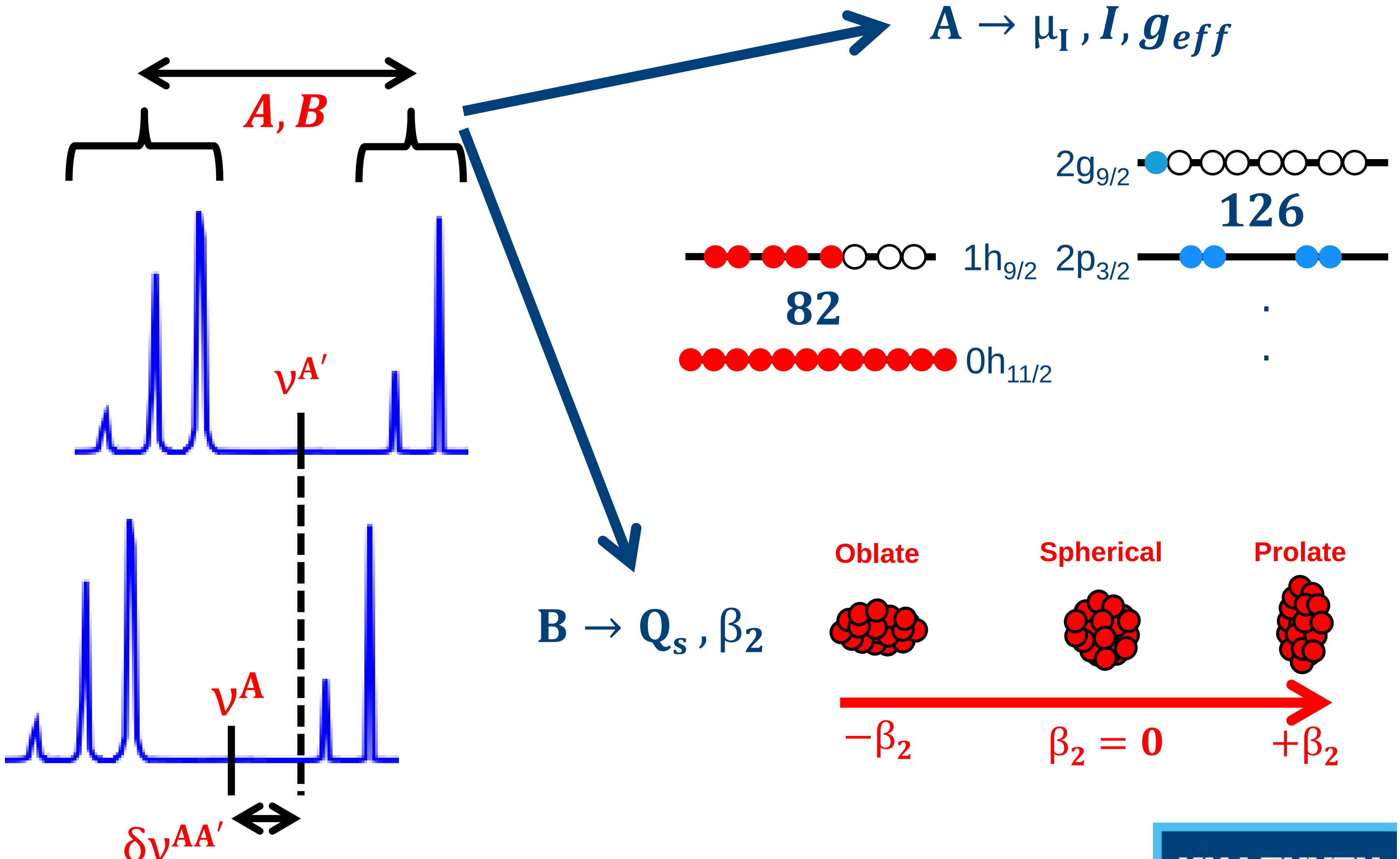
- The extracted parameters can be related to fundamental nuclear properties of the isotope.






KU LEUVEN

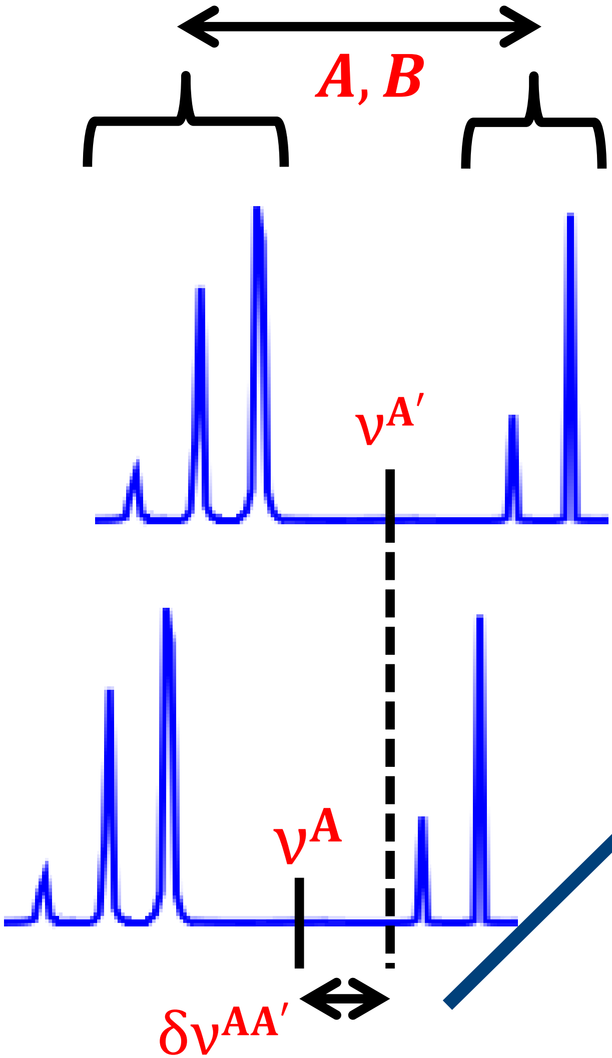
# Laser Spectroscopy



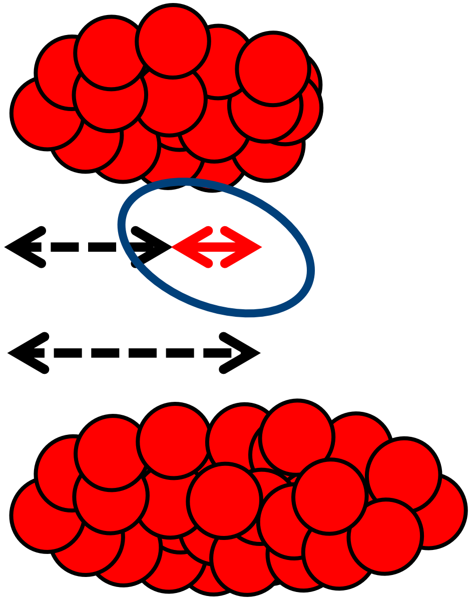



KU LEUVEN

# Laser Spectroscopy



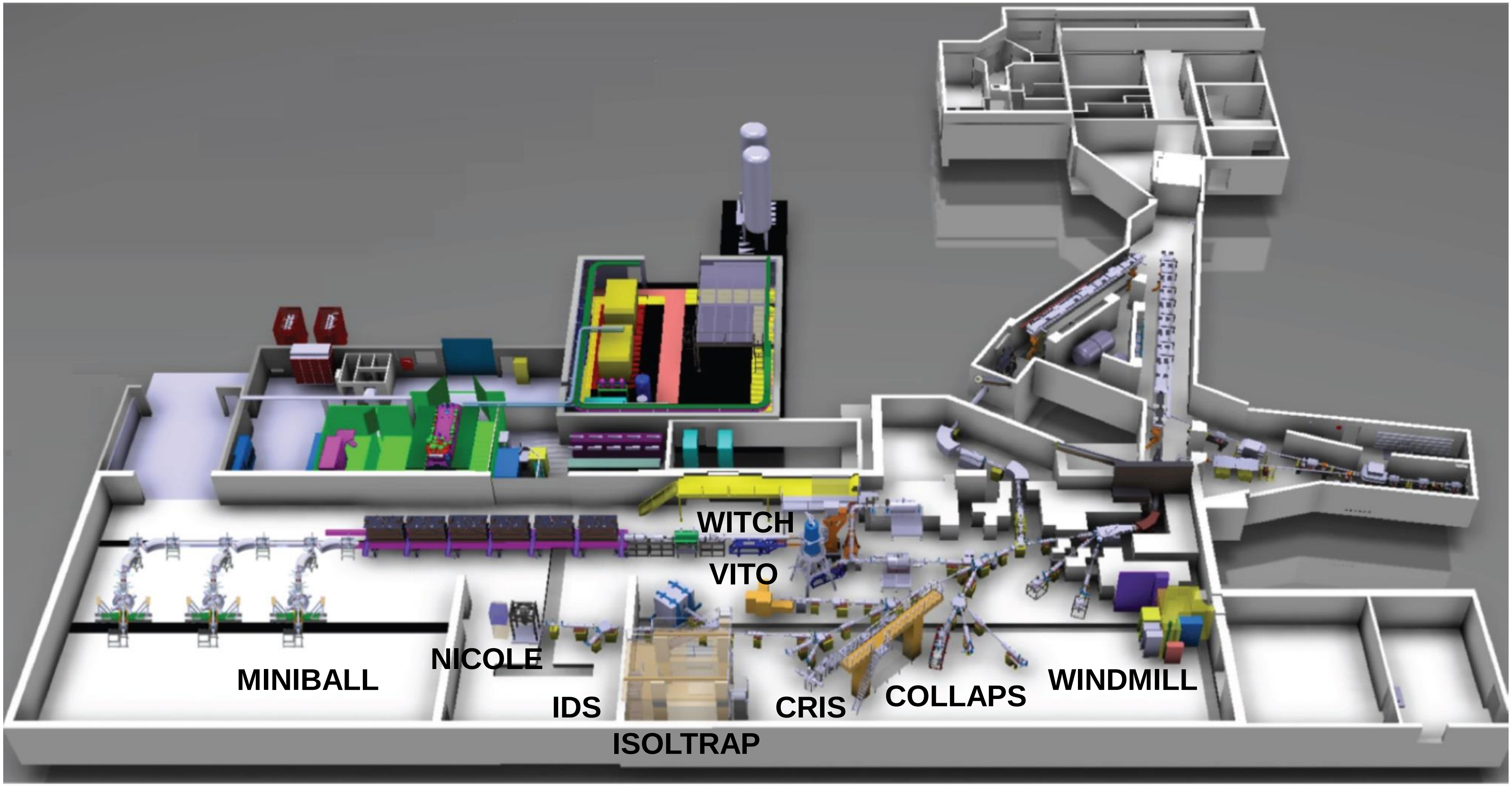

$\delta\nu^{AA'} \rightarrow \delta\langle r^2\rangle^{AA'}$





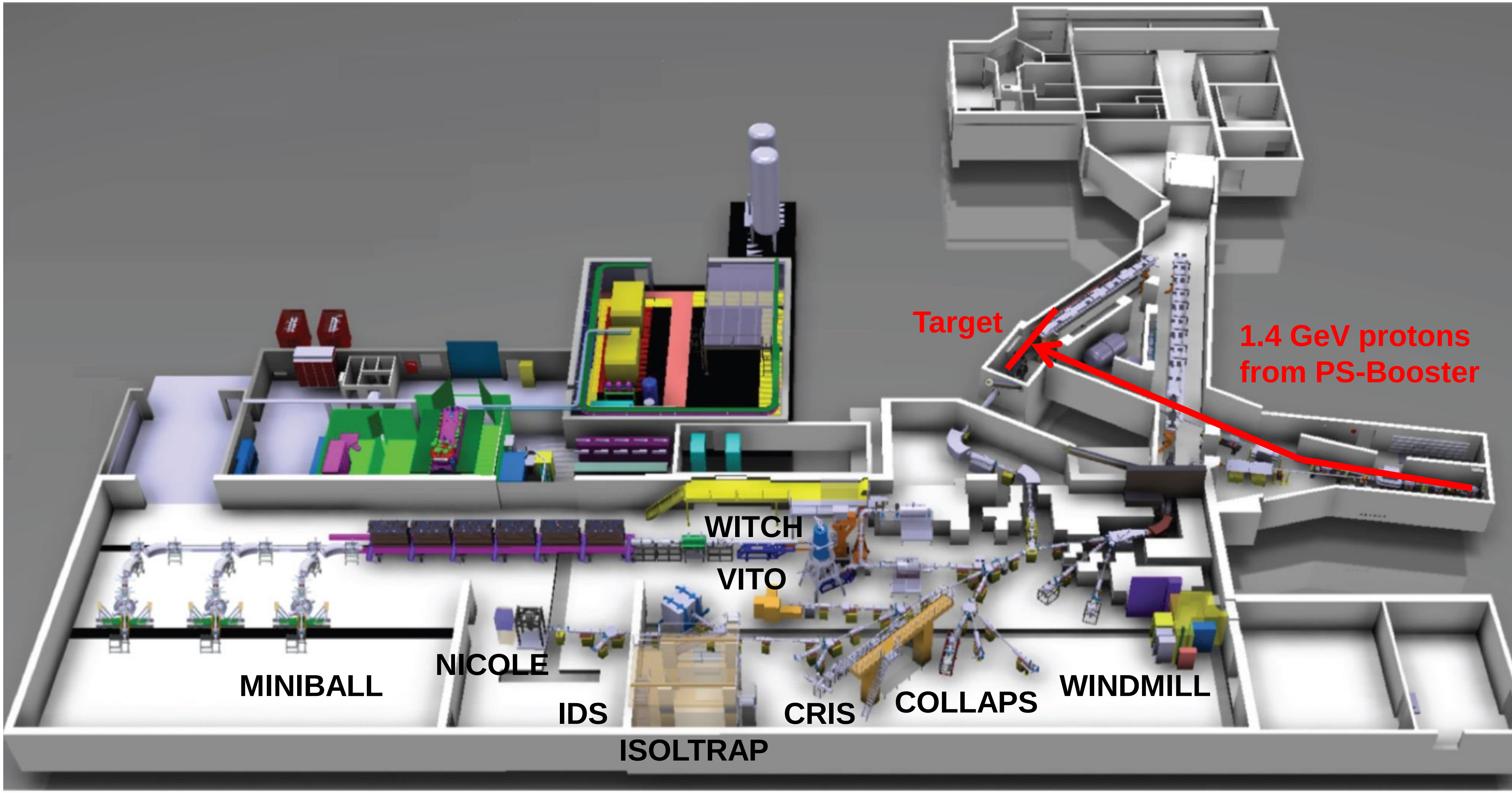
KU LEUVEN

# CRIS, CERN-ISOLDE



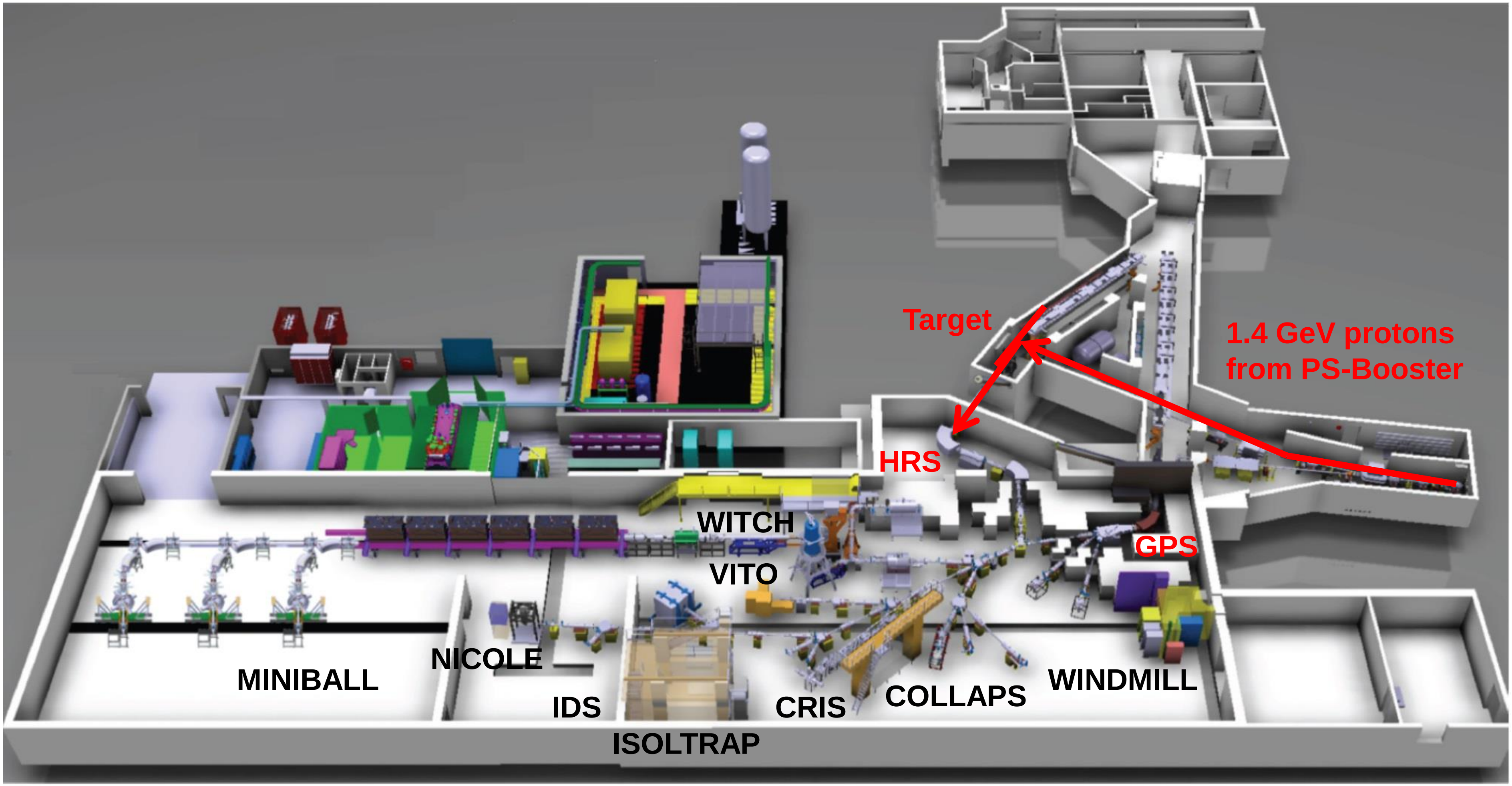

KU LEUVEN

# CRIS, CERN-ISOLDE



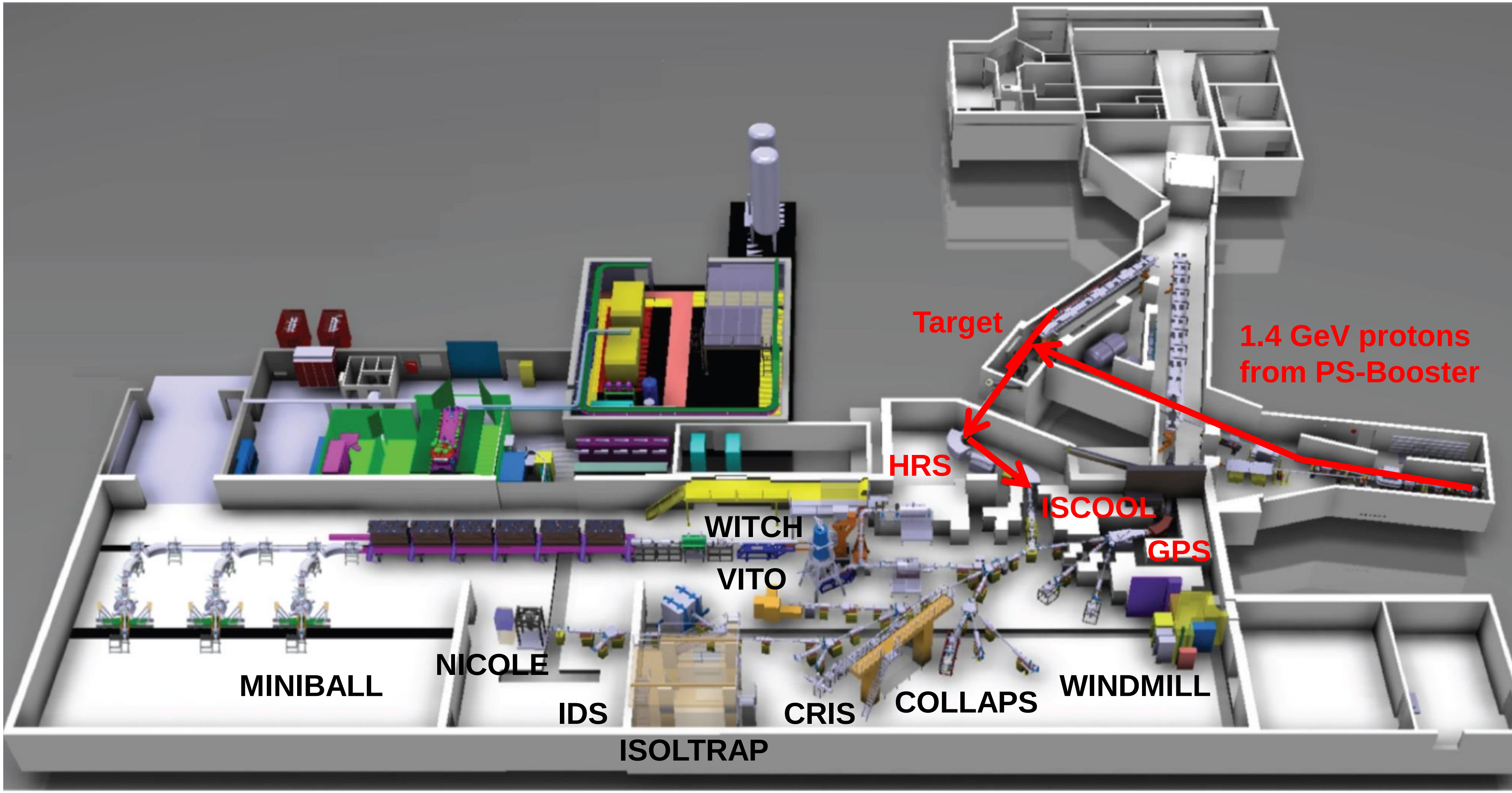

KU LEUVEN

# CRIS, CERN-ISOLDE



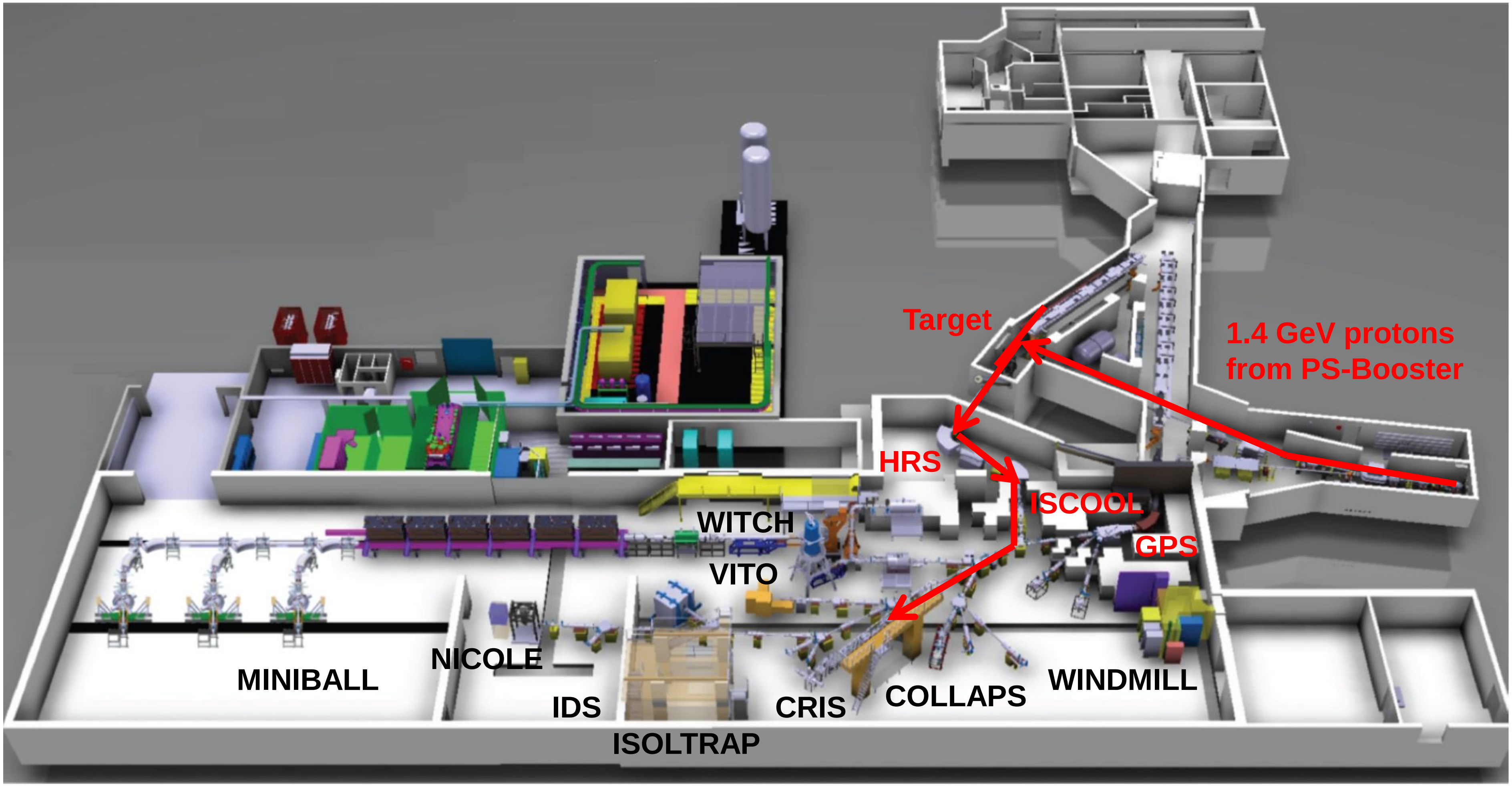

KU LEUVEN

# CRIS, CERN-ISOLDE



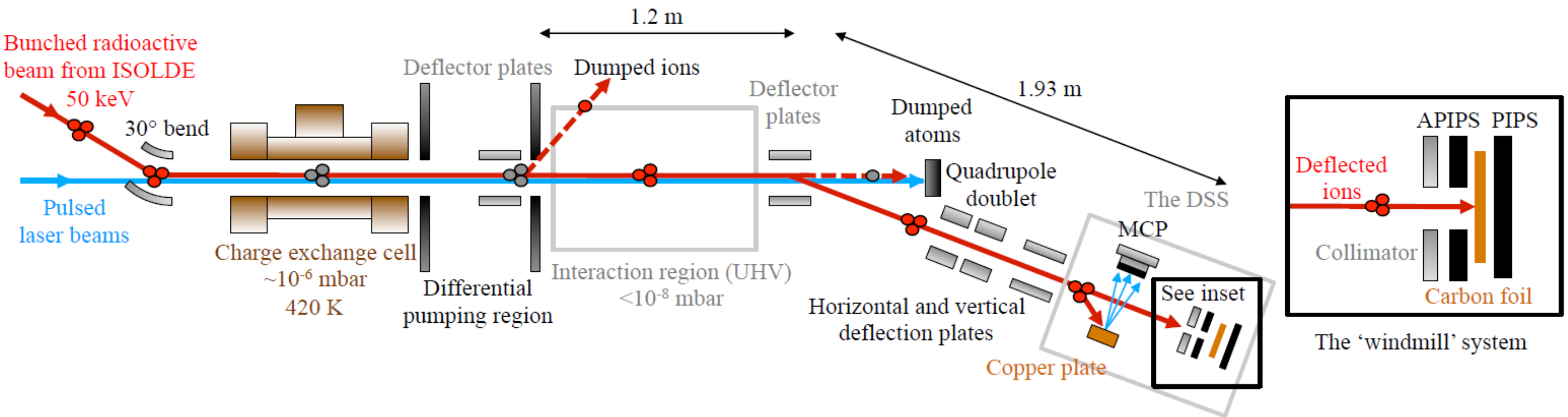

KU LEUVEN

# CRIS, CERN-ISOLDE




KU LEUVEN

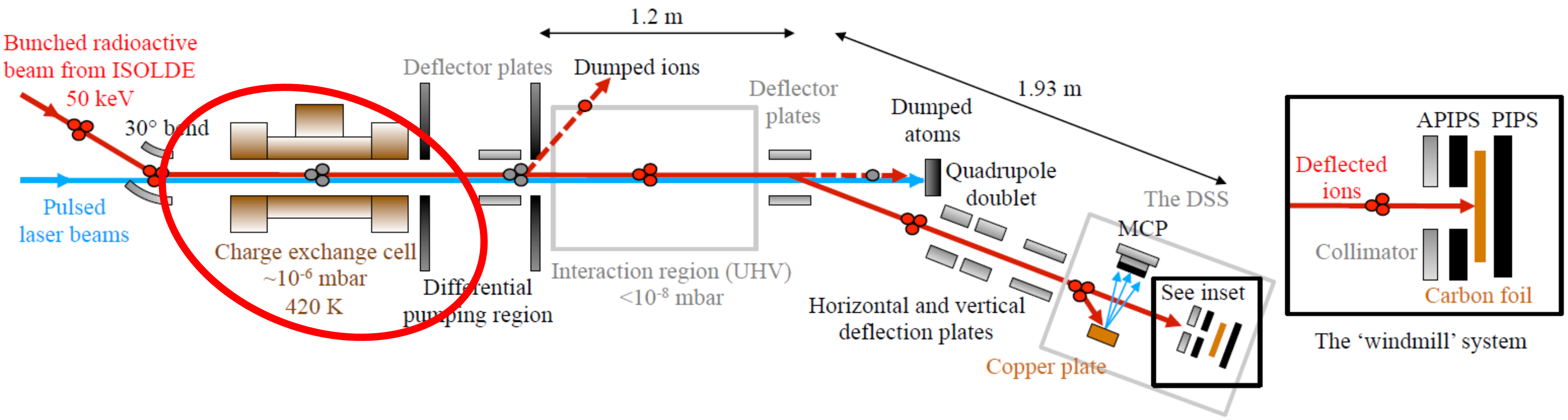
# CRIS, CERN-ISOLDE






KU LEUVEN

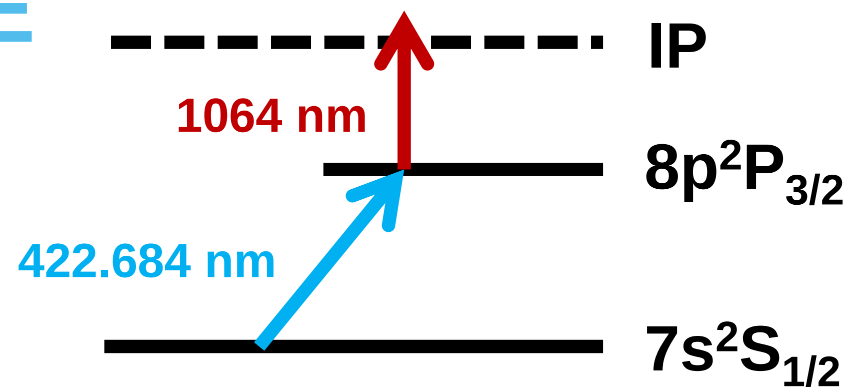
# CRIS, CERN-ISOLDE

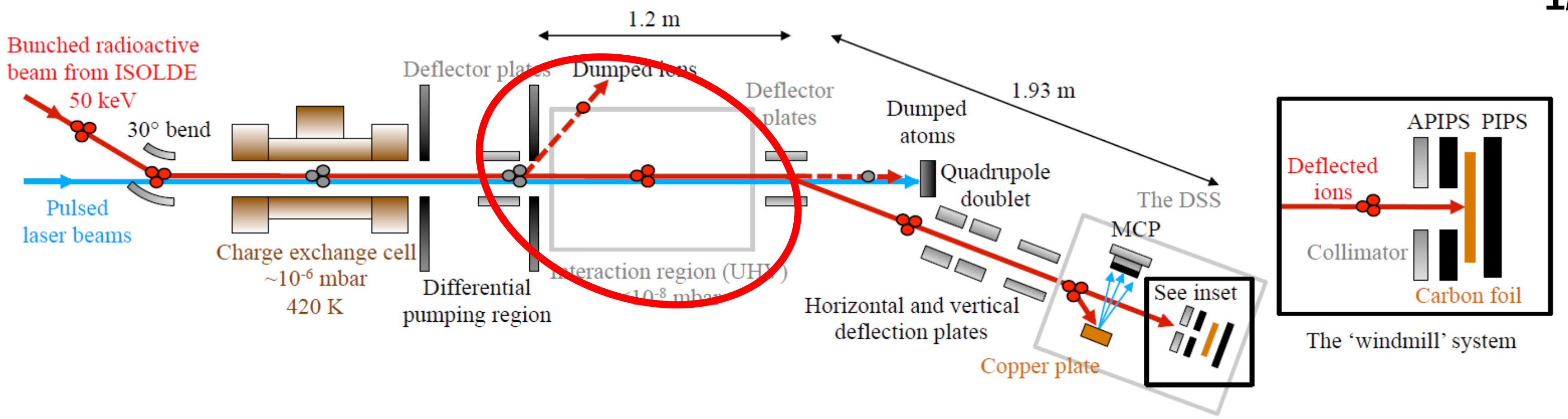




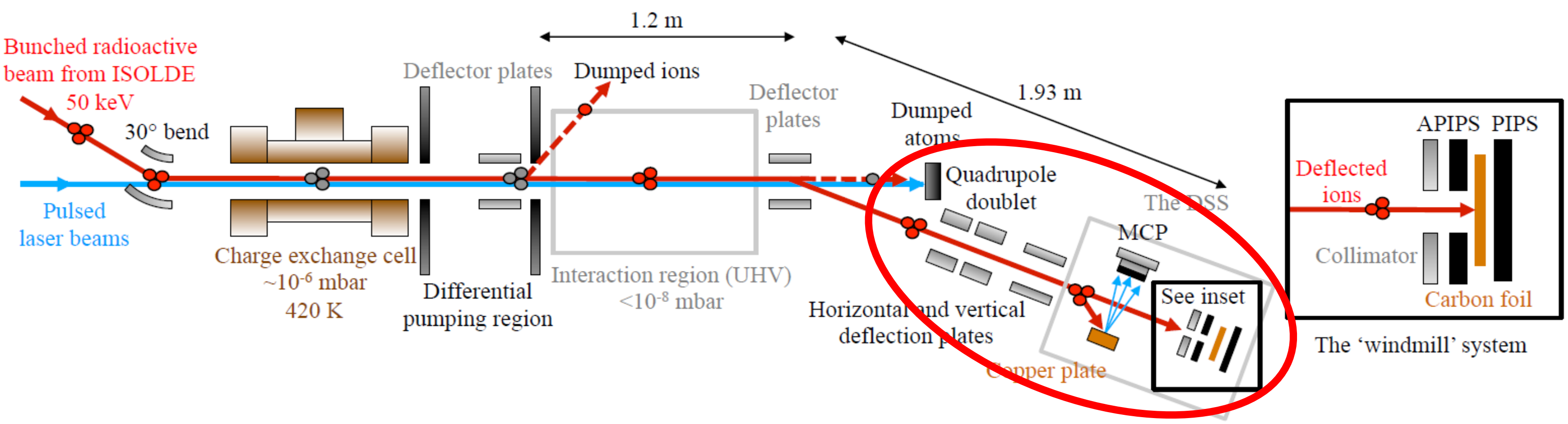

KU LEUVEN

# CRIS, CERN-ISOLDE



# CRIS, CERN-ISOLDE






KU LEUVEN

# IS471: Why francium?

- An ongoing experimental campaign is investigating francium isotopes at the CRIS setup.

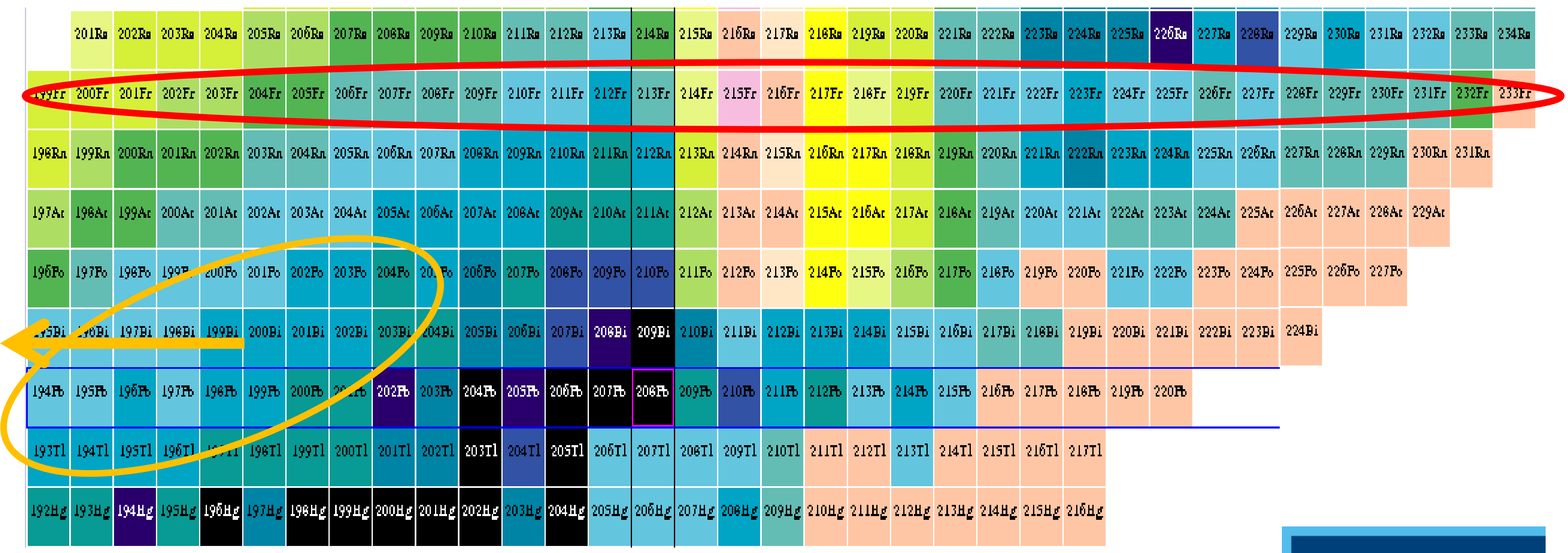
- It is thought that a variety of nuclear features exist in this isotopic region, depending on the proximity to Z = 82.


KU LEUVEN

# IS471: Why francium?

- An ongoing experimental campaign is investigating francium isotopes at the CRIS setup.

- It is thought that a variety of nuclear features exist in this isotopic region, depending on the proximity to Z = 82.

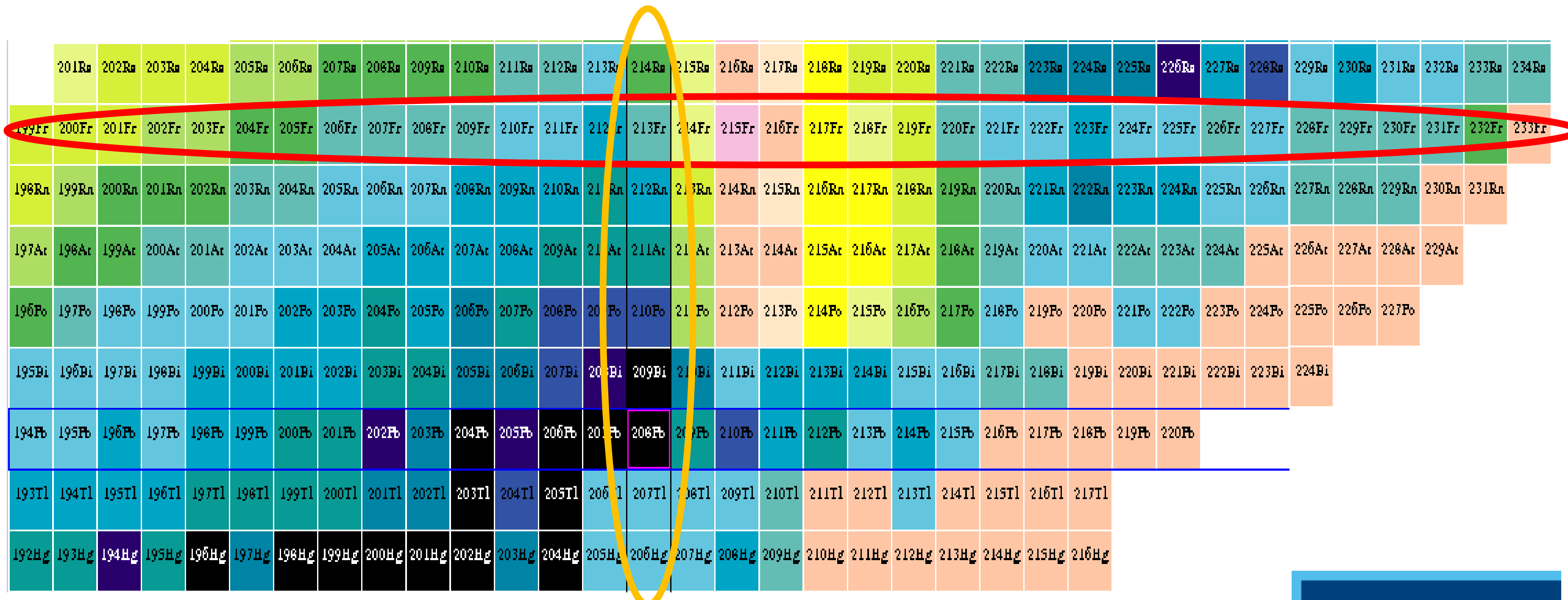



KU LEUVEN

# IS471: Why francium?

- An ongoing experimental campaign is investigating francium isotopes at the CRIS setup.

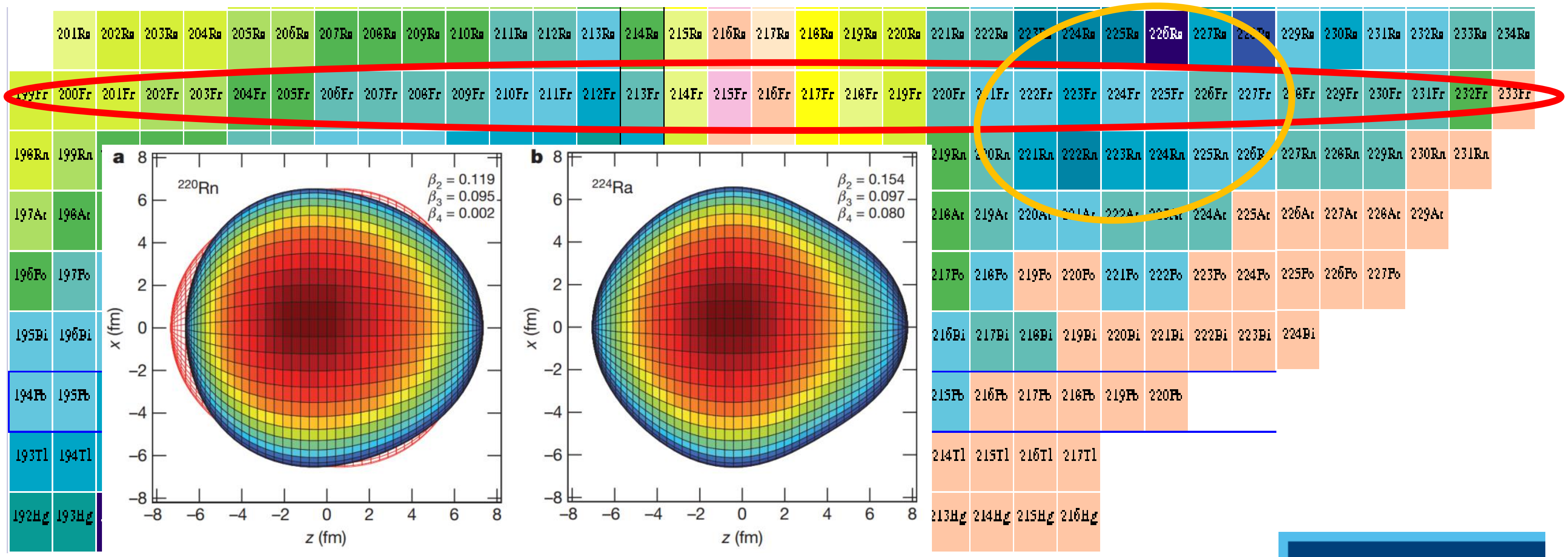
- It is thought that a variety of nuclear features exist in this isotopic region, depending on the proximity to Z = 82.



# IS471: Why francium?

- An ongoing experimental campaign is investigating francium isotopes at the CRIS setup.

- It is thought that a variety of nuclear features exist in this isotopic region, depending on the proximity to Z = 82.

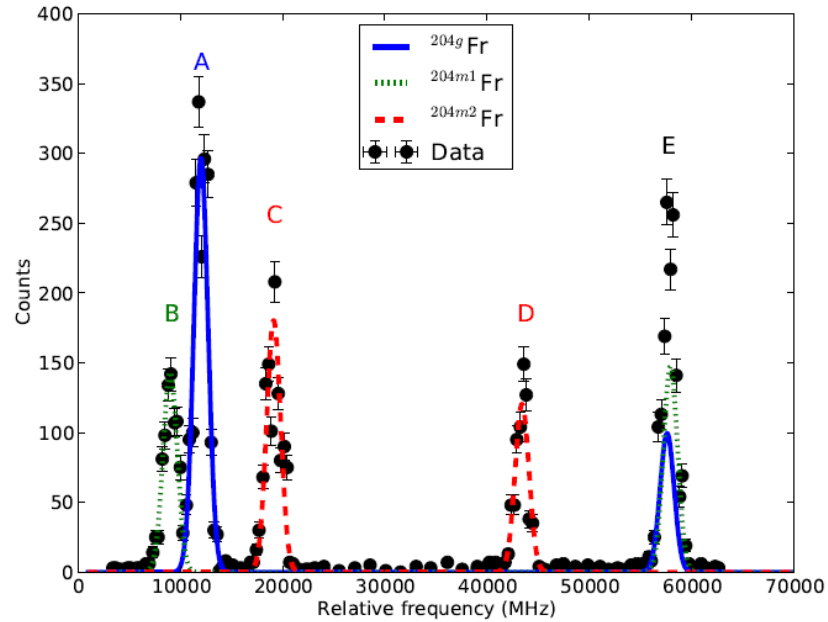


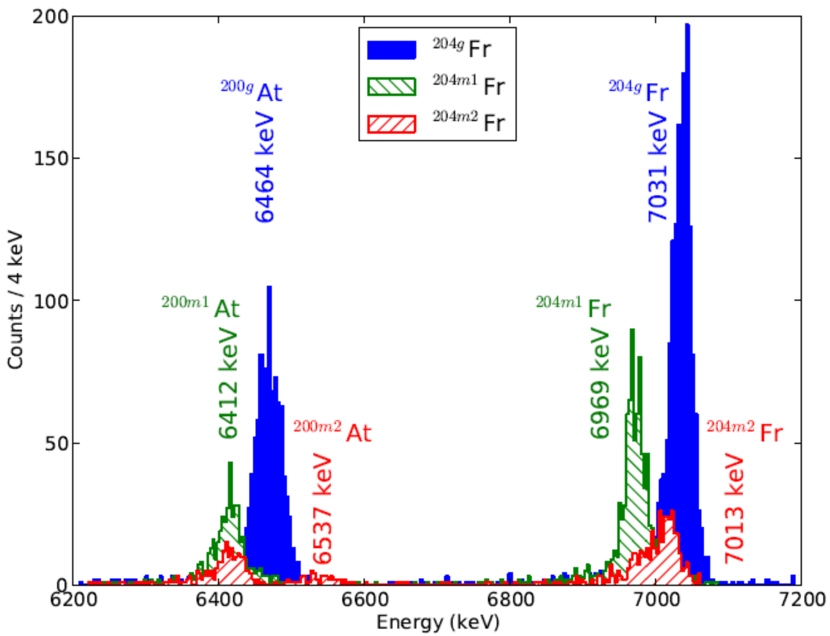



KU LEUVEN

# IS471: Neutron deficient

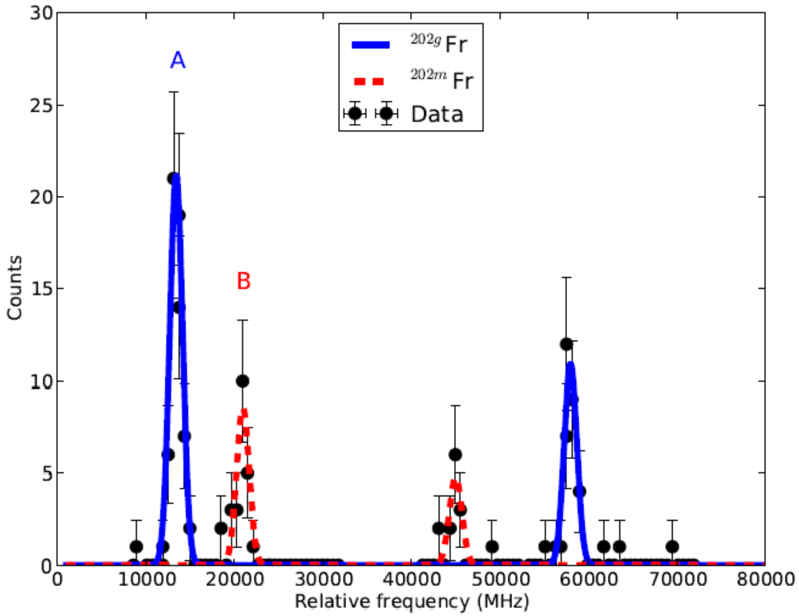

- Near-degenerate states can be de-tangled using laser-assisted nuclear decay spectroscopy.

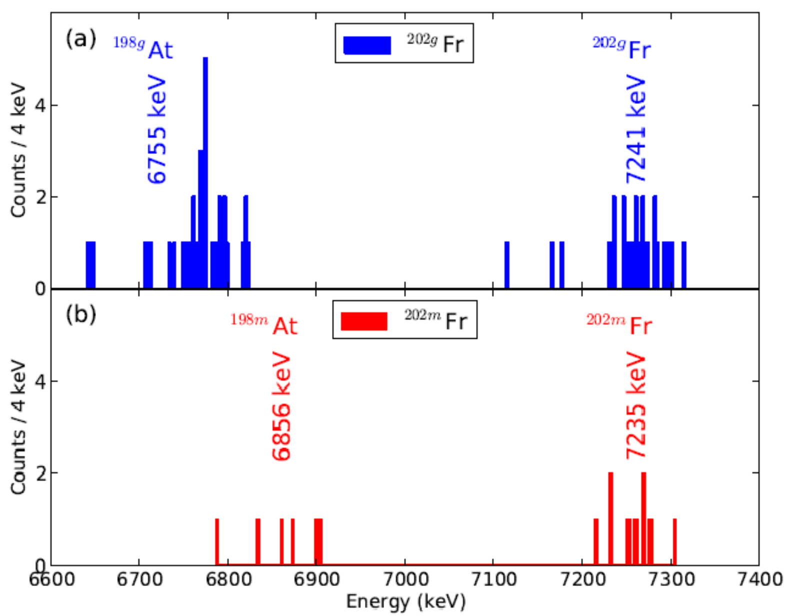



KU LEUVEN

# IS471: Neutron deficient

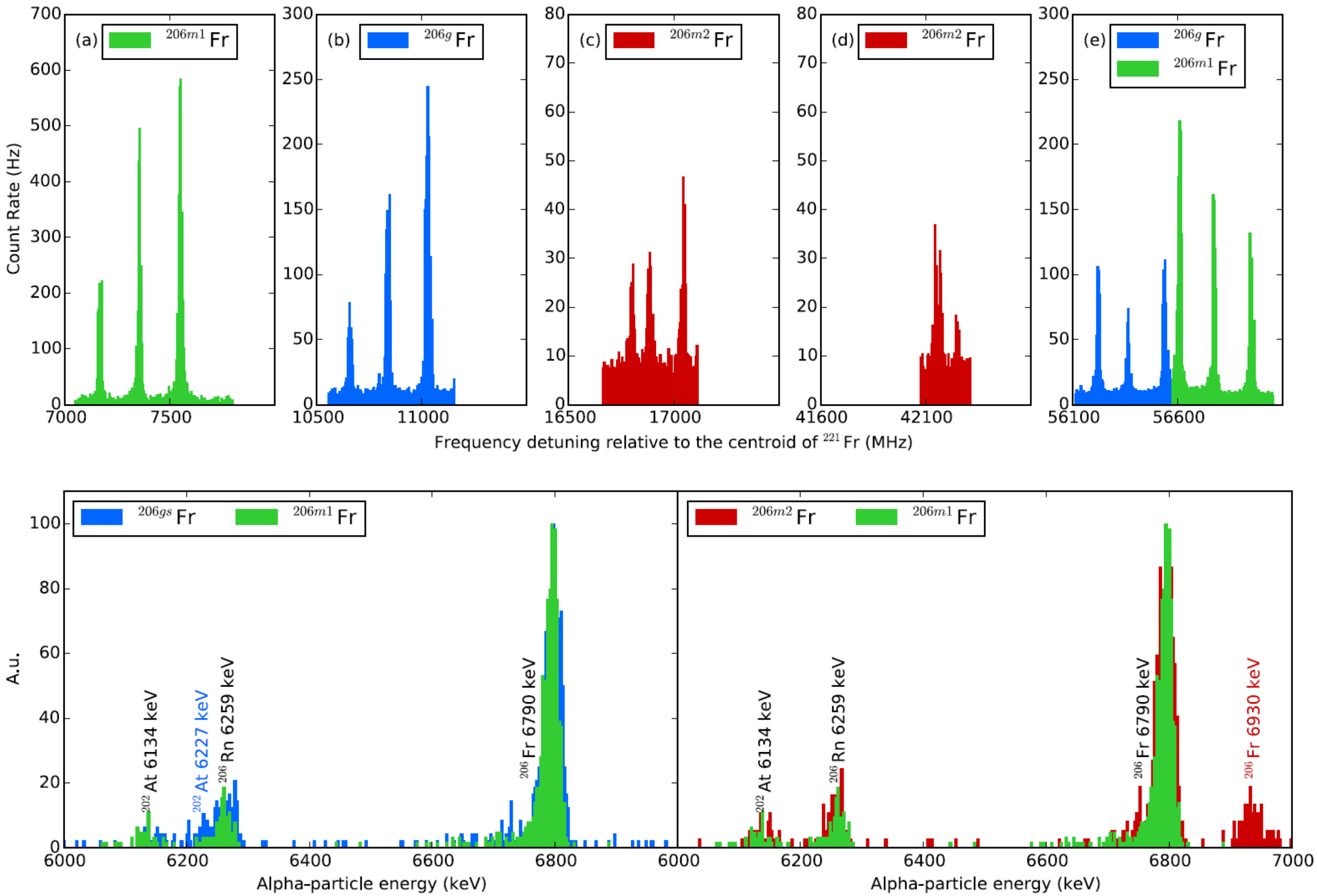





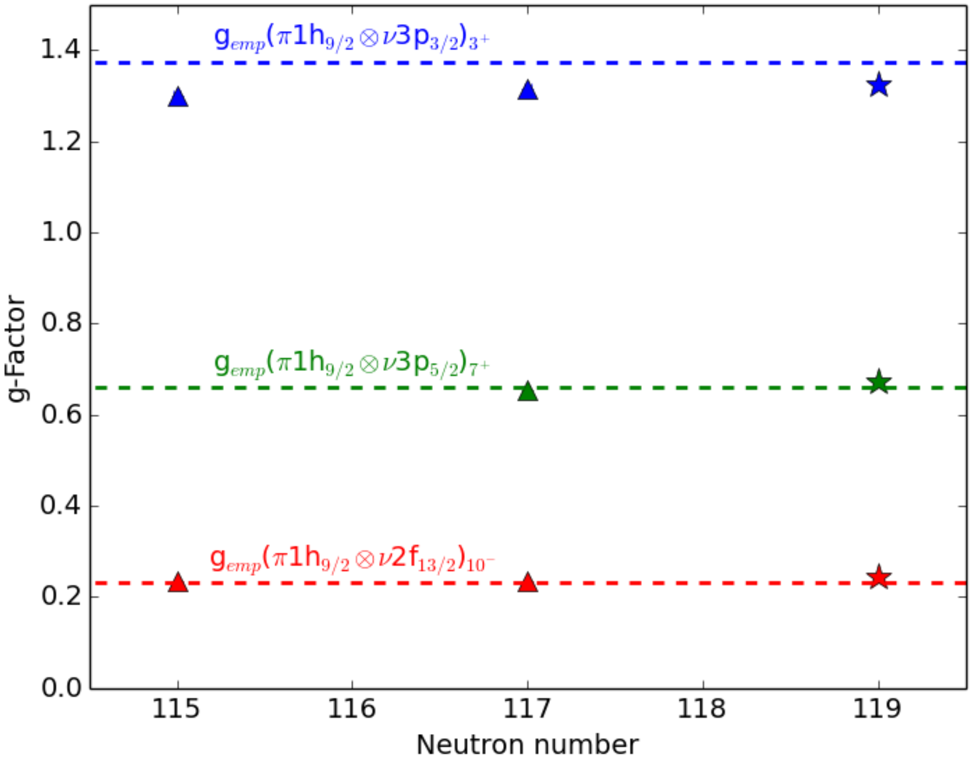

KU LEUVEN

# IS471: Neutron deficient



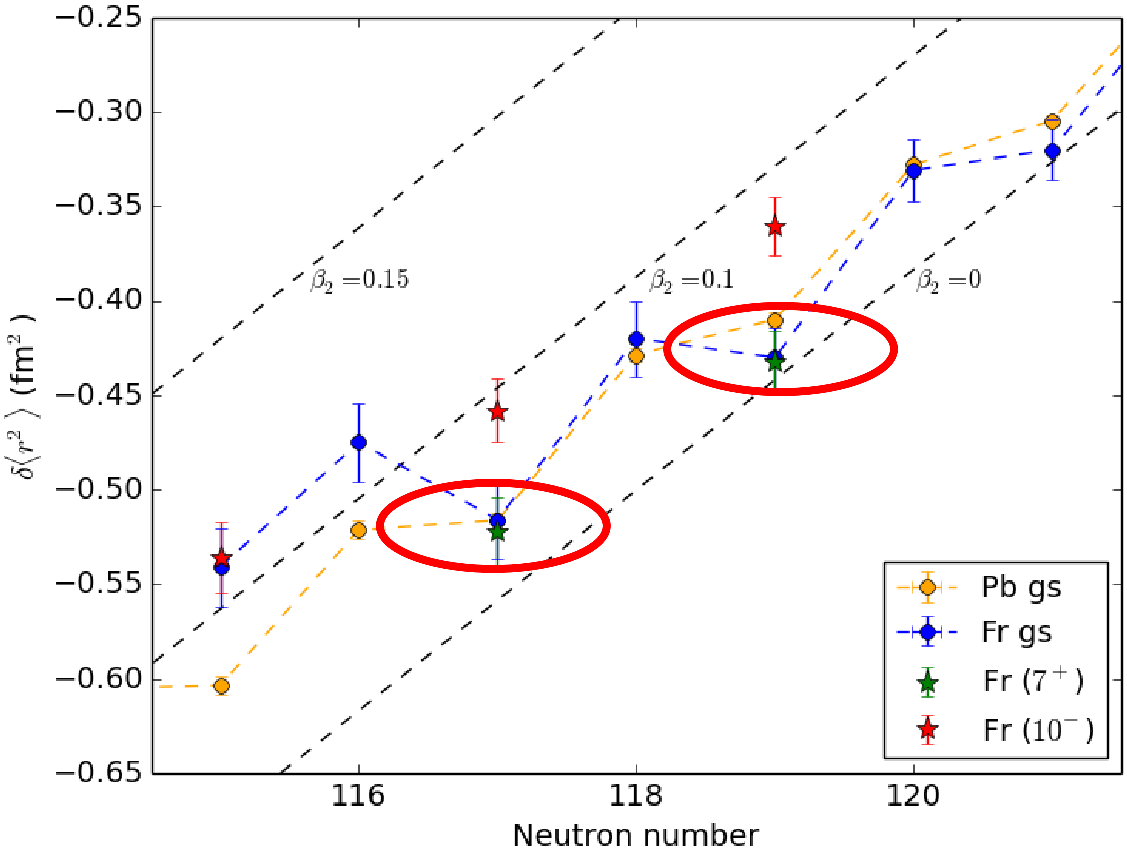
# IS471: Neutron deficient

$$g_{emp} = \frac{1}{2}\left[g_p + g_n + (g_p - g_n)\frac{j_p(j_p+1) - j_n(j_n+1)}{I(I+1)}\right]$$




- g-factor values are consistent with the additivity rule above.
- $g_{emp}$ values are calculated using magnetic moments of isotopes near to those being measured.

# IS471: Neutron deficient

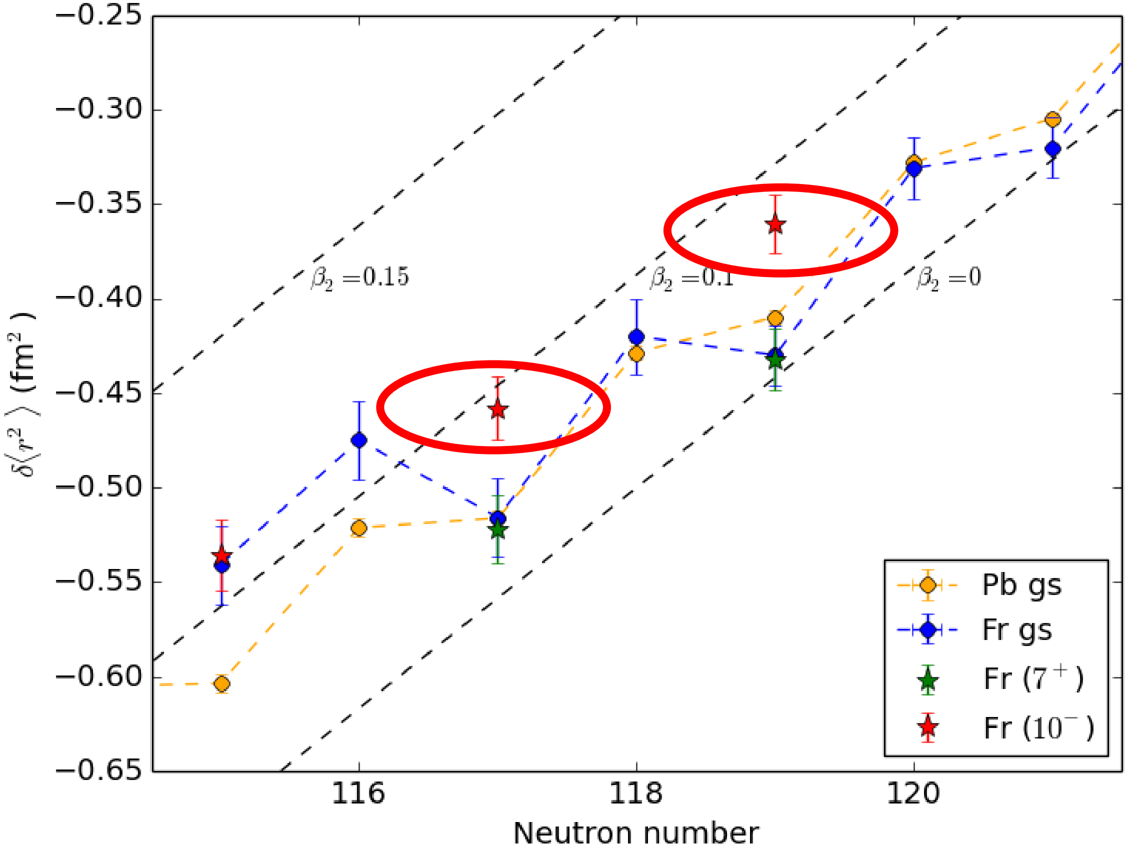



- $3^+$ and $7^+$ states exhibit spherical-like behaviour (in accordance with the Pb chain).



KU LEUVEN

# IS471: Neutron deficient

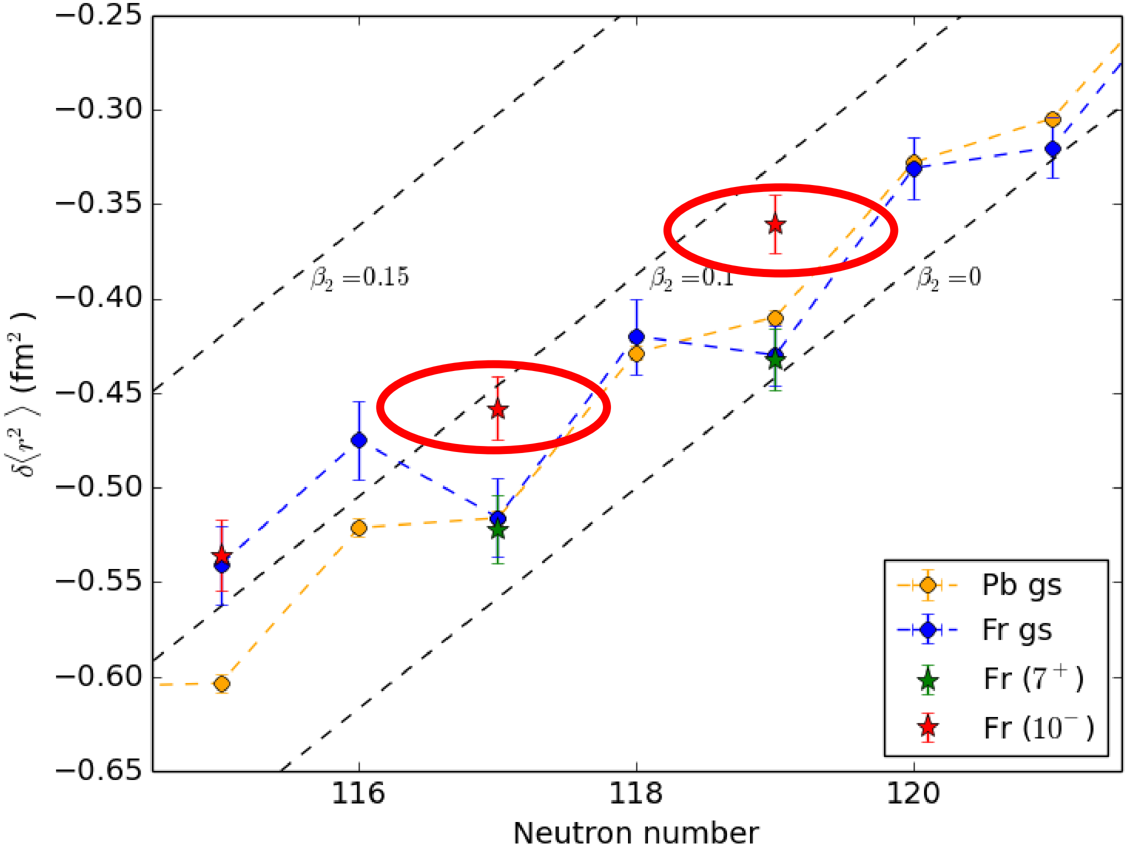



- $3^+$ and $7^+$ states exhibit spherical-like behaviour (in accordance with the Pb chain).
- However, the $10^-$ states are deformed.

KU LEUVEN

# IS471: Neutron deficient

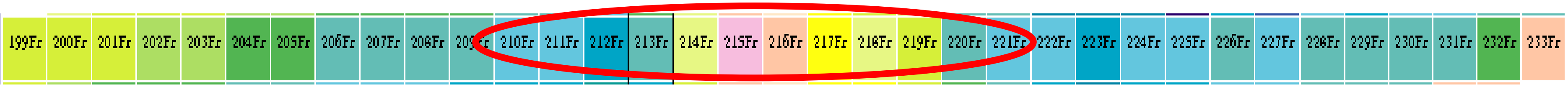
# Evidence of shape coexistence!




- $3^+$ and $7^+$ states exhibit spherical-like behaviour (in accordance with the Pb chain).
- However, the $10^-$ states are deformed.

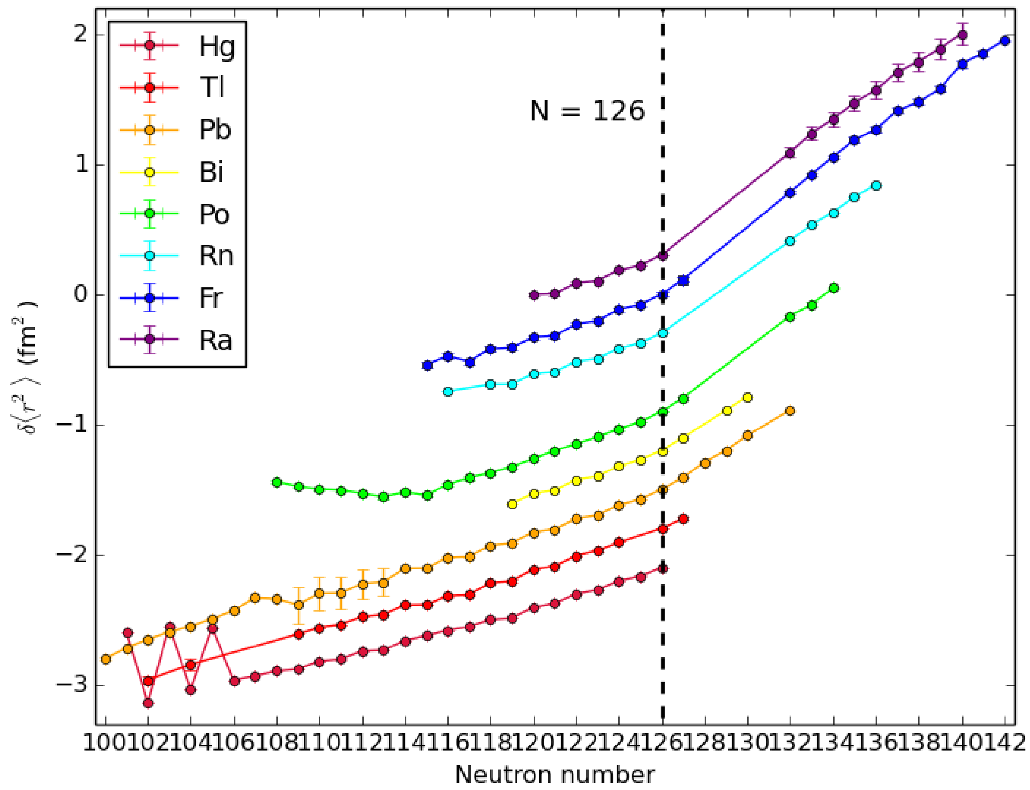
KU LEUVEN

# IS471: N = 126 shell closure




- The behaviour of these isotopes are dependent on their proximity to the N = 126 shell closure.

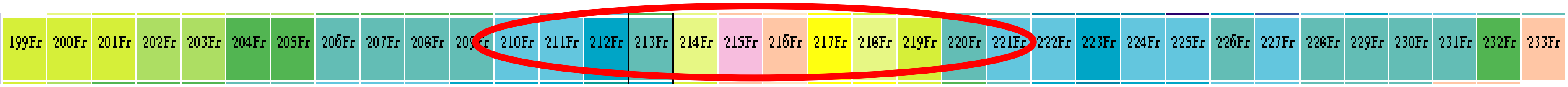
- In particular, the kink in the mean-square charge-radii values cannot be fully explained.





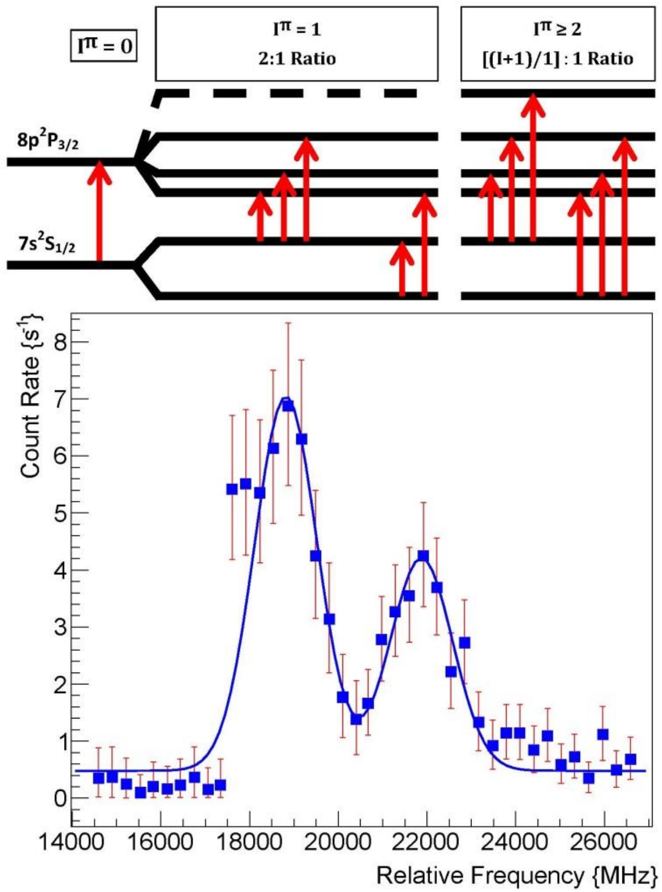

KU LEUVEN

# IS471: N = 126 shell closure




- The behaviour of these isotopes are dependent on their proximity to the N = 126 shell closure.

- In particular, the kink in the mean-square charge-radii values cannot be fully explained.

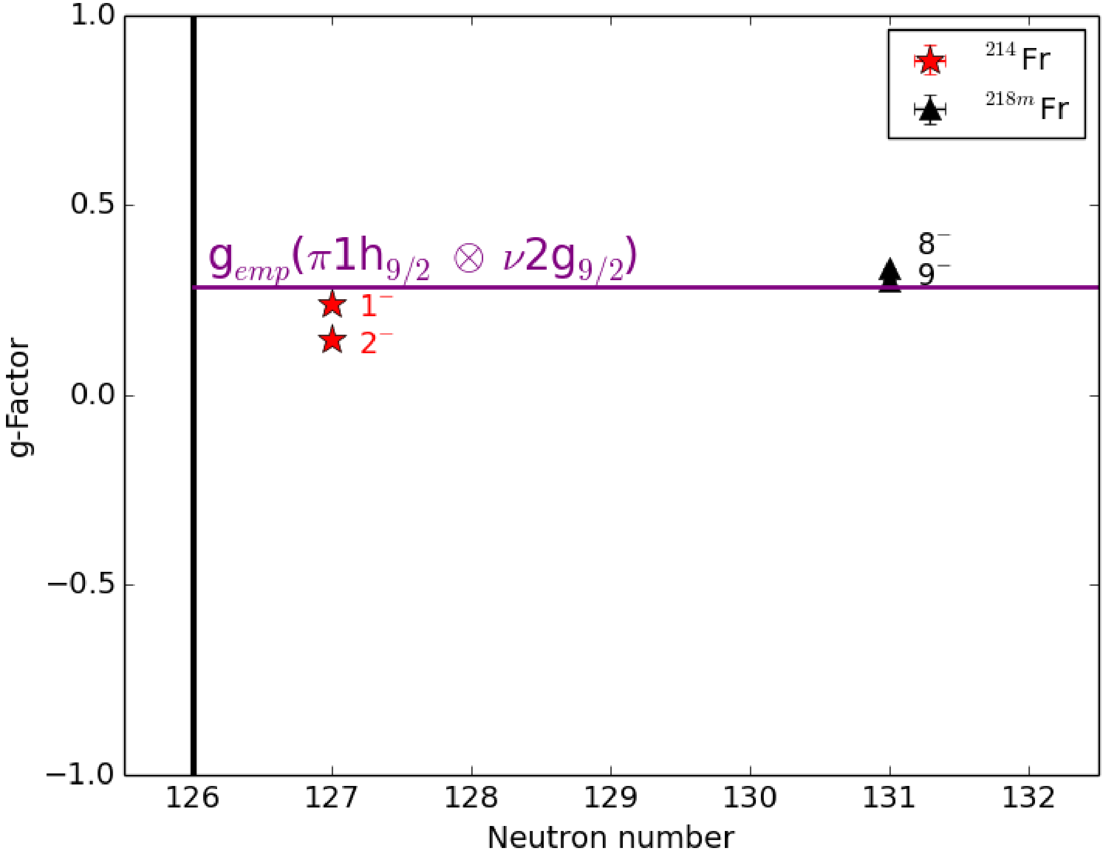





KU LEUVEN

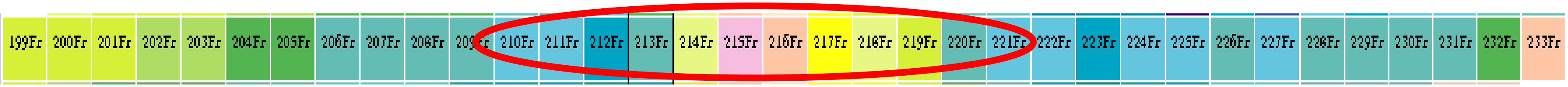
# IS471: N = 126 shell closure

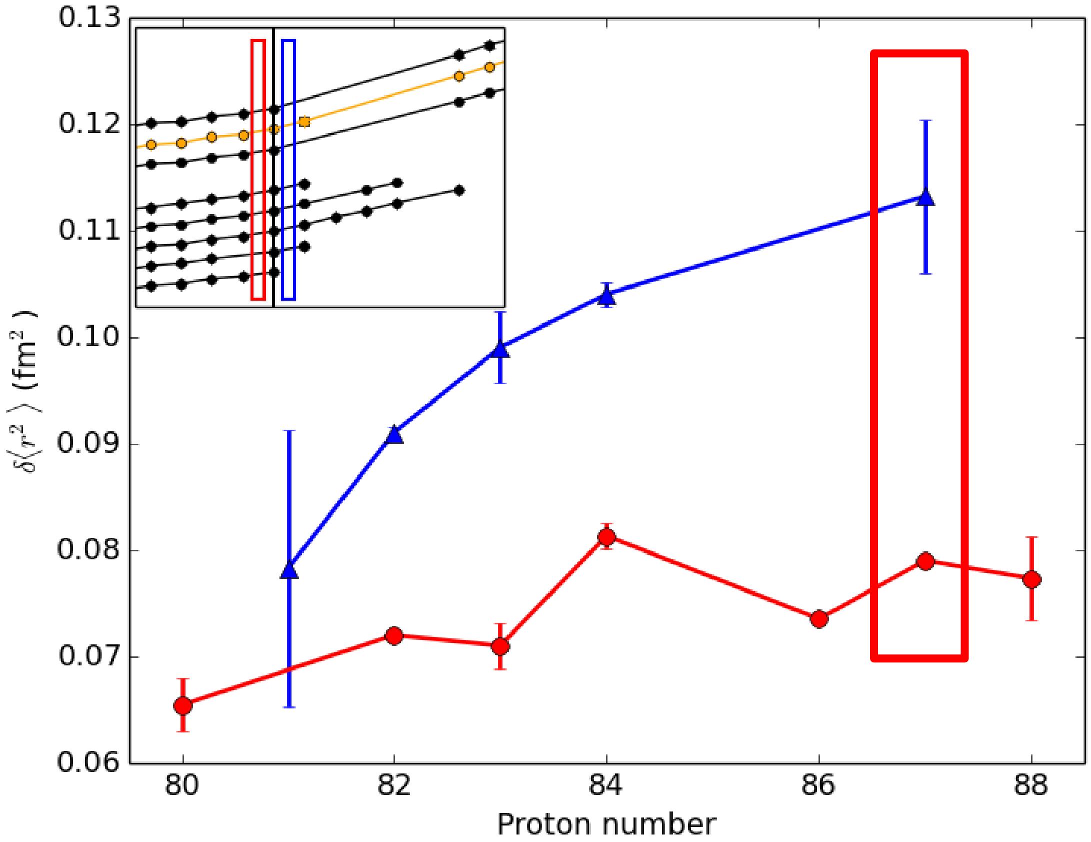
$$g_{emp} = \frac{1}{2}\left[g_p + g_n + (g_p - g_n)\frac{j_p(j_p+1) - j_n(j_n+1)}{I(I+1)}\right]$$




- As with $^{206}$Fr, g-factor values for $^{214}$Fr are consistent with the additivity relation.
- Suggests a tentative spin assignment of ($1^-$).

# IS471: N = 126 shell closure




- As the N = 126 shell closure is crossed, a kink is seen in the charge-radii values, depicted by gradient increase.

KU LEUVEN

# IS471: N = 126 shell closure

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 199Fr | 200Fr | 201Fr | 202Fr | 203Fr | 204Fr | 205Fr | 206Fr | 207Fr | 208Fr | 209Fr | 210Fr | 211Fr | 212Fr | 213Fr | 214Fr | 215Fr | 216Fr | 217Fr | 218Fr | 219Fr | 220Fr | 221Fr | 222Fr | 223Fr | 224Fr | 225Fr | 226Fr | 227Fr | 228Fr | 229Fr | 230Fr | 231Fr | 232Fr | 233Fr |

Physics Letters B 317 (1993) 9–13
North-Holland

PHYSICS LETTERS B

## Anomaly in the charge radii of Pb isotopes

M.M. Sharma, G.A. Lalazissis and P. Ring

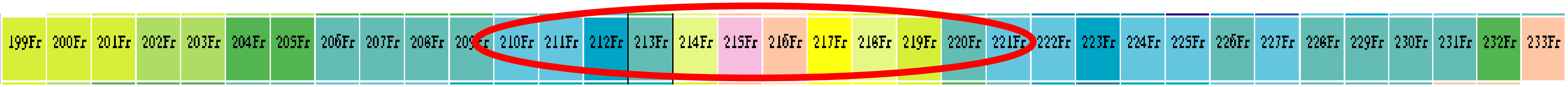
*Physik Department, Technische Universität München, D-85747 Garching, Germany*

Received 26 July 1993; revised manuscript received 30 August 1993
Editor: C. Mahaux

The anomalous behaviour of the charge radii of the isotopic chain of Pb nuclei has been studied in the relativistic mean-field theory. It has been shown that the relativistic mean field provides an excellent description of the anomalous kink in the isotopic shifts about $^{208}$Pb. This contrasts strongly from the Skyrme mean field, where the density-dependent Skyrme forces fail to reproduce the observed trend in the empirical data on the charge radii. The results have been discussed in the perspective of differences in the ansätze of the relativistic and the Skyrme mean-field theories.

KU LEUVEN

# IS471: N = 126 shell closure




PRL **110,** 032503 (2013) PHYSICAL REVIEW LETTERS week ending 18 JANUARY 2013

## Charge Radius Isotope Shift Across the $N = 126$ Shell Gap

P. M. Goddard, P. D. Stevenson, and A. Rios

*Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom*

(Received 9 October 2012; revised manuscript received 26 November 2012; published 15 January 2013)

We revisit the problem of the kink in the charge radius shift of neutron-rich even isotopes near the $N = 126$ shell closure. We show that the ability of a Skyrme force to reproduce the isotope shift is determined by the occupation of the neutron $1i_{11/2}$ orbital beyond $N = 126$ and the corresponding change it causes to deeply-bound protons orbitals with a principal quantum number of 1. Given the observed position of the single-particle energies, one must either ensure occupation is allowed through correlations, or not demand that the single-particle energies agree with experimental values at the mean-field level.

DOI: 10.1103/PhysRevLett.110.032503 PACS numbers: 21.10.Ft, 21.60.Jz, 21.30.−x, 27.80.+w

The evolution of charge radii across the isotope chart is one of the most basic nuclear structure observables, as it provides a particularly useful characterization of the proton distribution that can be accessed by a variety of experiments [1]. We define the charge radius isotope shift as the difference between the mean squared charge radius, $\langle r^2_{ch} \rangle$, of a series of isotopes and that of a given reference isotope

Letter, we propose a new mechanism to explain the existence of the kink in lead isotope shifts using density functional calculations supplemented by pairing effects.

On the theoretical side, mean-field models, or, equivalently, density functional theories have been widely applied to the systematic study of all observed and hypothesized nuclear isotopes [8]. Both the Skyrme-Hartree-Fock and

# IS471: N = 126 shell closure


PHYSICAL REVIEW C **91**, 021302(R) (2015)

## Effects of three-nucleon spin-orbit interaction on isotope shifts of Pb nuclei

H. Nakada[1,*] and T. Inakura[1,2]
[1]*Department of Physics, Graduate School of Science, Chiba University, Yayoi-cho 1-33, Inage, Chiba 263-8522, Japan*
[2]*Yukawa Institute of Theoretical Physics, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo, Kyoto 606-8502, Japan*
(Received 4 December 2014; published 18 February 2015)

We investigate the effects of the $3N$ interaction, which effectively adds a density-dependent term to the LS channel, on the isotopes shifts of the Pb nuclei. With the strength so as to keep the $\ell s$ splitting of the single-nucleon orbits, the density dependence in the LS channel tends to shrink the wave functions of the $j = \ell + 1/2$ orbits while making the $j = \ell - 1/2$ functions distribute more broadly. Thereby the kink in the isotope shifts of the Pb nuclei at $N = 126$ becomes stronger, owing to the attraction from neutrons occupying $0i_{11/2}$ in $N > 126$. The density dependence in the LS channel enables us to reproduce the data of the isotope shifts by the Hartree-Fock-Bogoliubov calculations in a long chain of neutron numbers, even without degeneracy between the $n1g_{9/2}$ and $n0i_{11/2}$ levels. We exemplify it by the semirealistic M3Y-P6 interaction.



KU LEUVEN

# Summary

- Recent work on francium isotopes at the CRIS setup have revealed a variety of nuclear features, analogous to that exhibited in other isotope chains.

- Work on $^{204,206}Fr$ revealed existence of shape coexistence in the neutron-deficient isotopes.

- A kink in the charge-radii value is seen in $^{214}Fr$ past the N = 126 shell closure, however more work needs to be done to interpret this mechanism.